RECENT DEVELOPMENTS IN EDDY-CURRENT MODELING

Harold A. Sabbagh, R. Kim Murphy, Anthony Chan,
Elias H. Sabbagh, Lai Wan Woo
Sabbagh Associates, Inc.
4635 Morningside Drive
Bloomington, IN 47408

and

Michael C. Warnes
Nuclear Electric Ltd.
Barnett Way
Barnwood, Glos GL4 7RS, ENGLAND

INTRODUCTION

In [1] we developed a volume-integral eddy-current model that is applicable to steam generator tubing. The model is now implemented in VIC-3D[1], and in this paper we present some results computed with it.

A WORD ABOUT VIC-3D

VIC-3D is a general purpose code that is designed to solve eddy-current problems in nondestructive evaluation by means of volume-integral equations. It solves axisymmetric problems, such as those typically found in steam generator tubing, in a module called Tube Support Plate. In this module, the problem is defined by means of a few parameters. Figure 1 illustrates the manner in which the parameters may vary in order to define problems ranging in complexity from a simple tube support plate with a magnetite gap to a tube with a non-uniform radius, support plate, magnetite gap, and sludge region.

A MODEL CALCULATION

Figure 2 illustrates a common situation, in which an axial flaw exists on the outer surface of a tube, and is centered under a ferromagnetic tube support that may even contain a layer of magnetite. The detector is a standard differential bobbin probe.

[1]VIC-3D is a registered trademark of Sabbagh Associates, Inc.

Review of Progress in Quantitative Nondestructive Evaluation, Vol. 16
Edited by D.O. Thompson and D.E. Chimenti, Plenum Press, New York, 1997

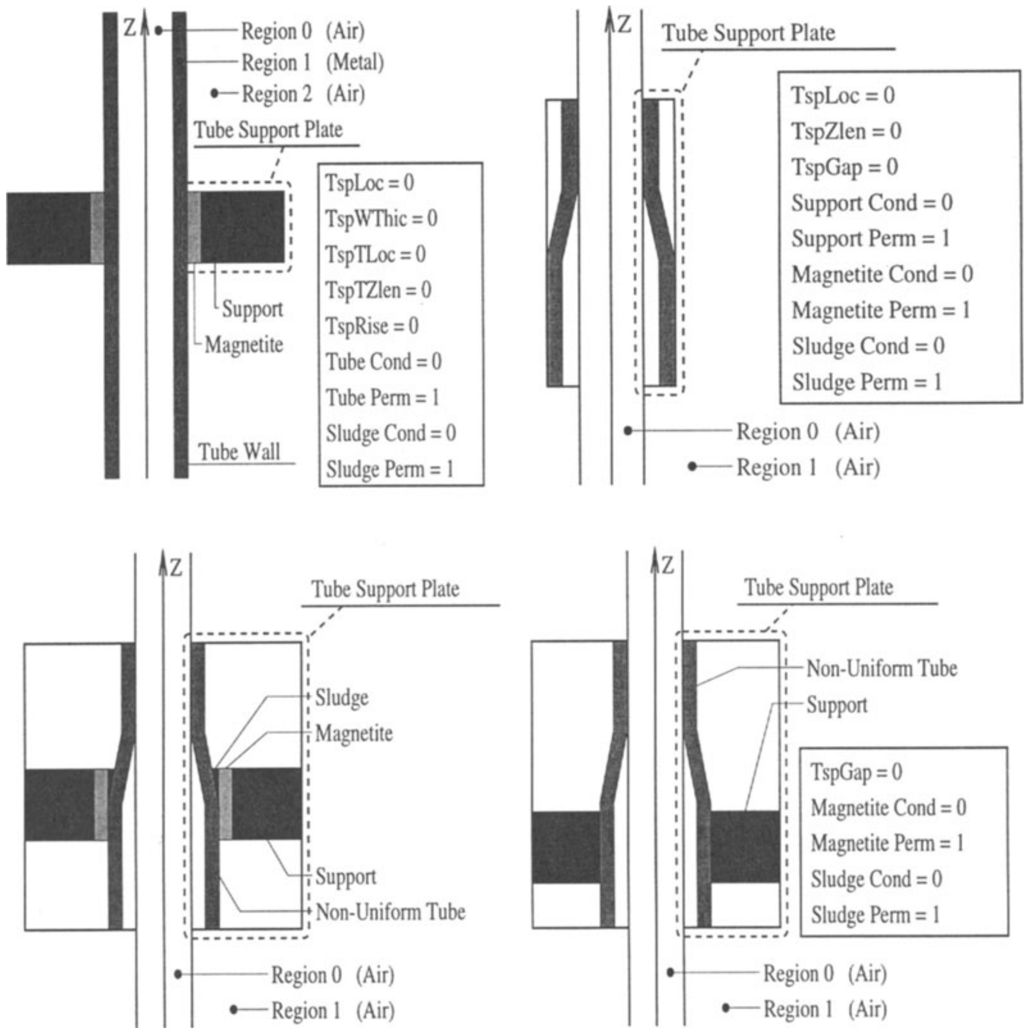


Figure 1: Examples of axi-symmetric regions modeled with the Tube Support Plate. Clockwise from upper left: 1. Tube support plate with magnetite gap; 2. Tube with non-uniform radius; 3. Tube with non-uniform radius and support plate; 4. Tube with non-uniform radius, support plate, magnetite gap, and sludge region.

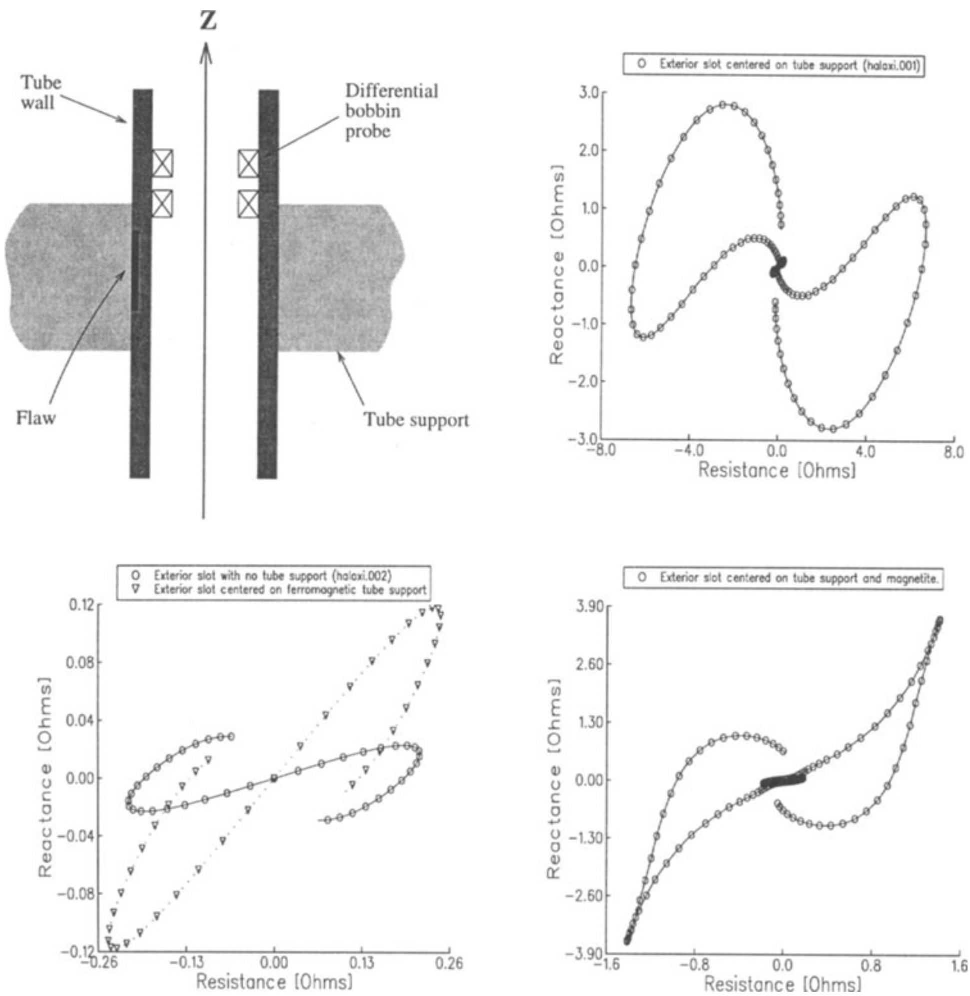


Figure 2: 1) An external axial flaw, centered under a ferromagnetic tube support is shown in the upper left. 2) The response of the differential bobbin probe to the flaw and tube support is shown in the upper right. The signal from the edges of the tube support dwarf the flaw signal, which is buried in the middle of the curve. 3) The flaw signal alone is shown in the lower left; the tube support signal has been subtracted ('balanced out'). Also shown is the flaw signal from a tube with no support. 4) The effect of a large magnetite layer on the curve in the upper right is shown in the lower right.

Table 1: Tube and probe specifications for Validation Problem No.1.

Tube Identification	PPDREF
Inner Diameter (ID) mm	15.6
Outer Diameter (OD) mm	17.6
Material Conductivity $\mu\Omega$cm	87
Probe Number	A.560 ULC(680)
ID(mm)	12.6*
OD(mm)	14.2*
Coil Height(mm)	1.3*
No. of Turns	40*
* Estimated Value	

Table 2: Defect dimensions for Validation Problem No.1.

% Through-wall Hole	Hole Depth(mm)	Hole Diameter(mm)
100	1.00	1.34
80	0.80	2.0
60	0.60	3.0
36	0.36	3.6
20	0.20	3.6

TWO VALIDATION PROBLEMS

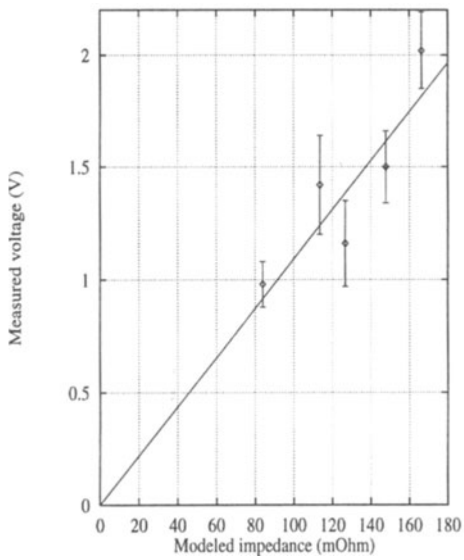
We have been validating the model and code for flaws in tubing, and in this section we present the results for two validation tests. The first test was performed at the Nuclear Electric Ltd. Engineering Division, Gloucestershire, England. Bobbin coil signals from blind (partially penetrating) and through-wall holes in two different sized Inconel steam generator tubes were measured with a standard eddy current test instrument (Zetec MIZ40) at two different frequencies--400 kHz and 680 kHz. We used VIC-3D to predict the results for one tube (labeled PPDREF) at 400 kHz.

The tube and probe specifications are shown in Table 1. The dimensions of the Zetec bobbin coil probe used in tube PPDREF were unobtainable from the manufacturer, and, therefore, estimated dimensions were used. This is a source of systematic error in the results.

The sizes of the holes were measured by taking replicas, which were sectioned, enlarged with a shadow graph, and measured. They are recorded in Table 2. While great care was taken in making the replicas and their measurement, the error in the hole depth and diameter may be as great as 0.05mm.

The signals from each defect were measured and then analyzed to give the peak amplitude and phase. Following the normal convention, the phase setting of the MIZ40 was adjusted at each frequency, so that the phase angle of a 100% hole was set at 40°.

Error bars on the amplitudes of the measured defect voltages have been estimated from the uncertainties in hole depth and diameter. Figure 3



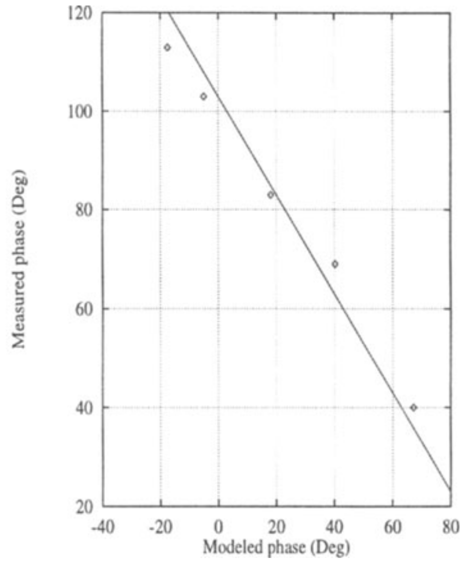


Figure 3: A comparison of the modeled and measured responses of the defects in Validation Problem No.1. The lines are guides to the eye; for phases, the slope is -1.

presents a comparison of these measurements with VIC-3D's modeled impedances. The lines drawn through the data are merely guides to the eye. However, the measured voltages and model predictions are clearly consistent, to within uncertainties. The slope of the line in the phase plots is -1; the deviation of the data points from a slope of -1 is apparently due to systematic effects, such as an incorrect estimate of the probe parameters, or the approximation, made in computing the matrix elements for the flaw, that the flaw lies within a flat workpiece.

In the second test, we compare model predictions with measurements performed at the Oak Ridge National Laboratory and communicated to us by Dr. C. V. Dodd. The test that we have modeled is shown in Figure 4. It consists of a bobbin coil within an aluminum tube ($\sigma = 2.58 \times 10^7$ S/m), which has four through-wall holes symmetrically placed around the circumference of the tube. The coil is excited at 500 Hz. In modeling this test, we compute the change in impedance due to one hole, and divide the measured impedance-changes by four.

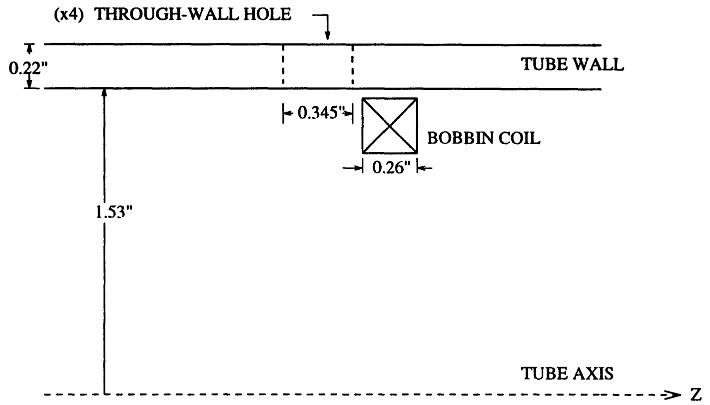


Figure 4: Validation Problem No. 2, consisting of a bobbin coil within an aluminum tube with a circular hole.

The magnitude and phase of the impedance-change due to the holes is shown in Figure 5. The differences between measurement and model calculation may be due to our "flat workpiece" approximation for the flaw matrix elements. Another possibility is that the signal from four holes is not simply four times the signal from a single hole.

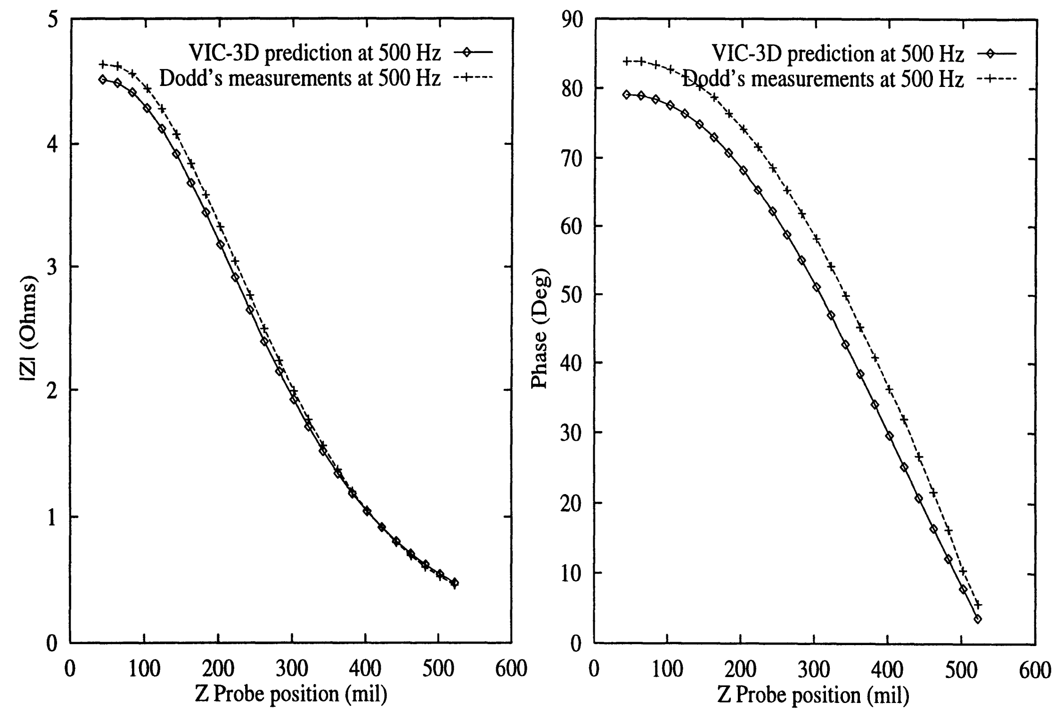


Figure 5: Comparison of measured and computed changes-of-impedances for Validation Problem No.2.

ACKNOWLEDGEMENT

The development of the axisymmetric tube support plate model was supported in part by the Electric Power Research Institute (EPRI), Palo Alto, CA.

REFERENCES

1. H. A. Sabbagh, R. Kim Murphy, J. C. Treece, and L. W. Woo, in *Review of Progress in QNDE*, Vol. 14, eds. D. O. Thompson and D. E. Chimenti (Plenum, New York, 1995), p. 283.